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Research Article

An Energy Consumption Monitoring and Control System in Buildings using Internet of Things

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ABSTRACT

In this paper a system to monitor and control the electricity consumption by means of Internet of Things (IoT) technology in buildings is presented. Wi-Fi smart plugs act as sensors to provide real-time power consumption data on a per device basis. This information is passed to a cloud-based platform via MQTT for further analysis. This mobile app is used to access the building's energy usage data in both real-time and historical, as well allowing control over connected devices from anywhere. The architecture of the system, i.e. hardware components, software infrastructure as well data flow are explained in details. The results show that the IoT-based smart plugs are providing accurate power consumption data with a low deviation. By providing electricity consumers with a greater level of detail on how and when they consume their power, this system can enable them to consciously exercise control over their energy consumption; which may result in reductions in cost as well as levels of inefficiency from the amount used.

1. INTRODUCTION

Electricity is a core utility in contemporary society, enabling homes to be lightened and industries, schools, businesses hospitals and transportation systems to function [1]. It is produced both from non-renewable sources like fossil fuels and renewable energy sources (RES) such as solar, wind. Nevertheless, the environmental footprint of electricity generation through fossil fuels is huge mainly due to resource depletion and pollution & waste production [2,3]. This has turned out to be a great concern when it comes to global electricity consumption. As a result, electricity consumption has become a major global concern. This has turned out to be a great concern when it comes to global electricity consumption. As a result, electricity consumption has become a major global concern. Many countries and scientific communities are actively seeking solutions to control and manage electricity use more effectively [4]. Saudi Arabia has intensified its efforts in this area. The country's 2030 vision aims to reduce energy consumption across various sectors by 20%, potentially saving about one million barrels of oil per day [5][6]. Traditional meters and smart meters are the two main types of current electricity monitoring solutions. Smart meters are those that can transmit data on their own without human intervention while traditional meters must be manually read [7]. However, the kind of solutions can only keep track of electricity used by a building as a whole but not individual gadgets. It is this limitation that makes it hard to find out the devices with high consumption levels that can be changed and also makes owners unaware of detailed usage trends. To solve these issues, new technologies are required for gathering and analyzing more detailed metrics on power consumption in buildings. A promising opportunity is being offered by smart plugs integrated into the Internet of Things (IoT). The technology will give information regarding utilization by each individual device connected, thus promoting higher consumer awareness which enables identification of appliances consuming too much energy [8]. The aim of this project is to create a mobile application making use of IoT and smart plugs to enable owners access their respective electric bills details. Decision-making will be better informed and could result in

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significant savings because users will know about the power consumed by their specific appliances through such an app. Our principal intention behind this pioneering initiative is therefore contributing towards ongoing entrepreneurship ventures so as to facilitate energy saving while empowering individuals with knowledge and techniques for effectively managing their electricity needs. Traditional smart meters found in most homes are now being replaced with advanced smart metering systems in relation to IoT architectures[9]. The system described in this project includes four main functions: on/off control, timer settings, power monitoring, and consumption reminders. This sensed device returns calculated current and sends message when overload happens. Smart meters of electricity have been developed but have disadvantages such as high cost, difficulty of installation etc contain a good sized upgrade of the prevailing metering infrastructure[10]. As the system collects detailed energy consumption data, ensuring the privacy and security of this information will be crucial. Future research should focus on developing robust encryption methods and secure data transmission protocols. As more devices and buildings are connected, the system will need to handle increasing amounts of data. Developing scalable cloud infrastructure and efficient data processing algorithms will be essential. Ensuring compatibility with various smart home devices and other energy management systems will be a challenge. Creating standardized protocols for device communication and data exchange should be a priority. Encouraging widespread adoption of the system may be challenging. Research into user experience design and effective methods for demonstrating the system's value to potential users will be important. As these systems become more prevalent, integrating them with the broader smart grid infrastructure will present both opportunities and challenges. This includes managing demand response and facilitating two-way communication with utility providers. Analyzing unstructured data from user interactions with the system could reveal insights into energy consumption behaviors. This could include studying the timing of device usage, frequency of app interactions, and responses to energy-saving suggestions. Incorporating unstructured data from weather reports, seasonal changes, and local events could provide context for energy consumption patterns and help in developing more accurate predictive models. Analyzing unstructured maintenance logs and repair records could help identify correlations between appliance efficiency and energy consumption, potentially leading to predictive maintenance features. Incorporating unstructured data about building characteristics (age, construction materials, renovation history) could provide context for energy consumption patterns and help in developing more tailored energy-saving recommendations [11]. Collecting and analyzing unstructured user feedback through surveys, reviews, and support tickets could provide valuable insights for system improvements and new feature development.

2. METHODOLOGY OF SMART GRID MANAGEMENT USING IOT

Use of IoT in the power industry is changing fast through enabling integration of renewable energy sources. Of late, the use of IoT connected green energy devices has reduced human input in EM systems. This technological development enables utilities to employ smart meters that monitor both green and non-green energy usage. Such architecture for IoT based EMS incorporates smart plug integration, a central hub as well as cloud-based infrastructure. Various brands' smart plugs are integrated using Bluetooth Low Energy (BLE) technology, while a central hub like the Insteon hub connects with the home router via Ethernet and communicates through radio frequency to avoid Wi-Fi signal overload. The cloud infrastructure built on platforms such as Amazon Web Services offers safe storage and processing power for data. These systems rely heavily upon collecting and processing data about watts, volts and amps from each individual plug utilizing machine learning algorithms that automatically determine consumption patterns of active devices. Some examples include real-time monitoring dashboards, historical data analysis tools, notification etc. Data collection and processing form the core of these IoT-based energy management systems. Real-time data on watts, volts, and amps are collected from each smart plug, with machine learning algorithms employed to automatically classify active devices based on their energy consumption patterns. The system integrates multi-modal data from various sources, including smart plugs, weather APIs, and user interaction logs, to provide comprehensive insights. This data is then presented to users through both mobile and web applications, featuring intuitive interfaces for device management, room/zone organization, and energy consumption visualization. These applications include real-time monitoring dashboards, historical data analysis tools, and notification systems for scheduled events, energy consumption alerts, and device status updates[12].

Advanced features of these systems include predictive analytics, automated control, and cost analysis. Machine learning models are used to predict future energy consumption and provide personalized energy-saving recommendations. Automated control features include scheduling and timer functionalities, as well as location-based automation using technologies like iBeacon. Cost analysis algorithms calculate anticipated monthly expenses based on energy consumption data and local electricity rates, helping users set and track energy-saving goals. To ensure system reliability and user satisfaction, thorough testing and validation processes are implemented, including system performance testing, user experience testing, and accuracy validation. Finally, robust security and privacy measures are put in place, including end-to-end data encryption, secure protocols for storing sensitive user information, and user controls for data sharing and privacy settings, ensuring compliance with relevant data protection regulations.

2.1 System Regulation

To be cost-effective, the hardware side utilizes Mokosmart Wi-Fi smart plugs as its primary sensors that can support devices up to 2400W and connect directly to the modem through Wi-Fi. The mobile application uses Samsung Android phones.

Amazon EC2 is part of a software infrastructure designed for cloud computation which acts as an MQTT Broker to receive data from smart plugs. The MQTT protocol supports data transmission between smart plugs and the cloud server. It's crucial for the system to manage its data well. In Jupyter Notebook custom Python script reads information from smart plugs with the help of the MQTT protocol. The Firebase platform saves user information and data from smart plugs. Python scripts are used for analyzing this received data in order to calculate daily and monthly consumption for each device/building along with upcoming electrical costs. This information can be accessed via a mobile app made using Android Studio 2020.3.1.The system integration process involves configuring smart plugs to connect to the EC2 cloud service, implementing Python code for data collection, connecting EC2 to the Firebase database, and integrating the mobile application with Firebase[13]. The data flow is regulated from smart plugs publishing power data to the MQTT Broker, through data processing and storage, to retrieval by the mobile application. Security measures include secure MQTT communication, encrypted data storage, and user authentication. The system is designed for scalability, supporting multiple smart plugs per user and capable of handling increasing data loads as adoption grows. This system regulation outlines the key components, their interactions, and the processes involved in the proposed smart energy monitoring system. It provides a framework for implementing a secure, scalable, and efficient solution for collecting and analyzing energy consumption data[14]. Blockchain technology with smart energy monitoring systems using the IoT lays a sound foundation for decentralized and secure energy management. We present in this study a new smart socket system based on the blockchain paradigm that utilizes DLT's features to improve data integrity, security and user autonomy in residential energy tracking. Real-time power consumption data and important events are recorded there as immutable transactions for every smart socket assigned a unique ID on the blockchain network. Secured with a smart contract at the point of data submission, this method guarantees that consumers will know on time about their energy consumption and any possible problem as questions sent to an address are automatically checked by reading measures from each telecounter [15]. The proposed architecture comprises NodeMCU (ESP8266) for Wi-Fi communication and blockchain connectivity along with a GSM Module as backup for cellular text messaging. This resilient configuration enables to cross-verify the data transmission securely and it provides opportunity for peer-to-peer energy trading between connected smart meter households. One of the most interesting use-cases is that it can run automated demand response programs through smart contracts, so adjust energy consumption to grid conditions and user preferences (which may make peak load reduction easier thereby optimizing overall energy). The integration of blockchain technology with IoT-based smart energy monitoring systems in the residential sector presents a promising avenue for enhancing energy management and security. This study aims to evaluate the feasibility and effectiveness of such an integration, focusing on several key aspects that could potentially revolutionize household energy consumption and data protection. One of the primary objectives is to examine the level of data security and user privacy disruption that this integrated system might introduce. As households become increasingly connected, concerns about data protection and privacy have grown. By leveraging blockchain's inherent security features, we hope to address these concerns and provide a more robust framework for protecting sensitive energy consumption data. Another crucial aspect of this research is the investigation of peer-to-peer energy trading possibilities[16]. The decentralized nature of blockchain technology could potentially enable direct energy transactions between households, bypassing traditional intermediaries and potentially reducing costs for consumers. Furthermore, we aim to assess the performance capabilities of this system by comparing the potential peak demand reduction achievable through a smart contract-based automated demand response program. This could provide valuable insights into how such a system might alleviate strain on the power grid during high-demand periods. The study will also verify the scalability and quality metrics of the system using available blockchain networks that support real-time household-level metering. This is crucial for understanding how the system might perform when implemented on a larger scale. The findings of this research could have far-reaching implications for the advancement of smart energy services. By informing technological progress in this area, we hope to contribute to the transformation of household electricity demand, enhance data protection measures, influence consumer attitudes and behaviors, and potentially improve grid operations in residential environments. The Internet of Things (IoT) has already begun to revolutionize various industries, providing unprecedented visibility and control [17]. In the energy sector, this could translate to more accurate predictions of service quality and potential disruptions. The healthcare industry, too, has seen significant advancements due to IoT technologies, particularly when combined with new insights into the human genome.

In the context of energy management, mixed-integer linear programming (MILP) has emerged as a powerful tool for solving complex optimization problems. This approach involves modeling energy-relevant planning and optimization challenges as MILP problems, where some variables are real numbers and others are integers. This method allows for more nuanced and effective solutions to energy management challenges. As we move forward with this research, we anticipate that the integration of blockchain and IoT in smart energy systems could pave the way for more efficient, secure, and user-friendly energy management in the residential sector. The potential for peer-to-peer trading, enhanced data security, and more effective demand response programs could significantly alter the landscape of household energy consumption and grid management. A particularly advantageous characteristic of the MILP approach is that it is a natural framework for incorporating dynamic and synthetic data and for communicating commands and decisions in real time. Rapid communication and decision-making are based on working with IoT devices—like the ubiquitous Raspberry Pi and Arduino modules plus lots of other local controllers—that in turn work with the digital twins of electricity and heat systems [18].

Smart Metering's potential cannot be fully realized unless the Advanced Metering Infrastructure (AMI) has also been set up. Why? Because AMI serves as the eponymous backbone for two-way communication between smart meters and their associated utility companies -- and, in this instance, we hardly need remind ourselves, the two-way communication that is the sine qua non for interaction between human beings and smart devices to unfold is not exactly via the device appearing on a utility's customer-facing portal or interface; rather, a completely different interface is responsible for bringing about that elusively "smart" condition, and its ephemerality should not be too lightly dismissed when thinking about the promise of Smart Metering[19]. This setup enables two-way data flow, which is crucial for the system to work effectively. AMI doesn't just collect data - it captures, stores, and forwards it to a central hub for processing. But there's more to AMI than just data handling. It's designed to play nice with Home Area Networks (HANs), creating an open system that brings smart metering right into people's homes. One project that's making waves in this field is OPEN Meter. They're working on hammering out a set of open, public standards for AMI. Figure 1 explains how it all fits together.

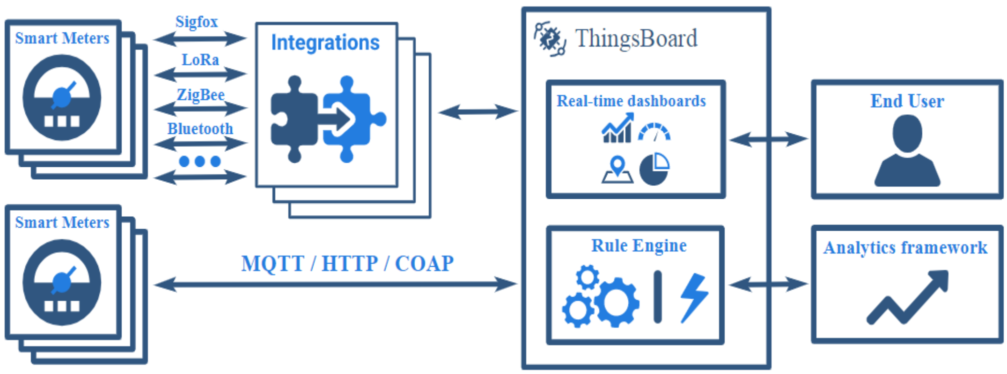

Fig. 1. MQTT platform for sending data over internet

MQTT enables devices to transmit (publish) data related to specific topics to a central server acting as an MQTT message broker [20]. This broker then distributes the information to client devices that have previously expressed interest (subscribed) in those topics. Topics in MQTT are structured similarly to hierarchical file paths [21], making them easily understandable to humans. Clients have the flexibility to subscribe to either specific levels within a topic's hierarchy or use wildcard characters to receive updates from multiple levels simultaneously [22].

3. SMART GRID ARCHITECTURE

In this system, we used Arduino Uno as the controller. All those components are connected in a box where the wall outlet is placed above the box. In addition, MQTT (Message Queuing Telemetry Transport) is used for bridging the gap between controller and the user [23]. MQTT makes users possible to control the smart wall outlet and get the report of power usage in their household. In this system, Adafruit IO is used as MQTT broker (server) [24] due to its simplicity and friendly interface. Data is sent and stored in Adafruit IO and can be viewed or controlled from user devices. When users are using the electricity in their house, but they are away, they can easily turn it on or turn it off with their Smartphone device that directly connected via MQTT. The Measuring Unit collects the AC current from the ACS712 current sensor, which gives the sinusoidal waveform a direct graph, which using the variable resistance, the machine regulates the strength of the sensors c entered on the load handling of the machine. Measurement systems have a button to automatically initiate a link to the qualified authorities. Three phases are identified: supply, storage/management, distribution, which almost never follow linearly over time, and are largely dependent on each other. The first two phases are strategic for a community/country and are at the origin of its political and economic movements. Think of the supply of natural gas, oil, electricity from other nations or economic realities, the opportunity to have "home" energy sources or to optimize the power output of engines, power generation plants and transformation processes. The users also can set how long they want to set the smart wall outlet on with the timer [25]. For example, when users want to charge their hand phone, but they want to sleep, they still can charge it without being afraid to waste the power usage [26] because they can estimate the time and after that the smart wall outlet will automatically disconnected to the electricity. The server establishes TCP/IP affiliation [27] with MCU foremost, so starts receiving information thread, being accountable for receiving the corresponding data; once the thread has processed the info and displayed then hold on it within the information server [28] . Once affiliation is successfully created, the ensuing task usually is to scan the info thread, scan correspondent information from the buffer, then write the data to a table, avoid the loss of information as shown in Figure 2.

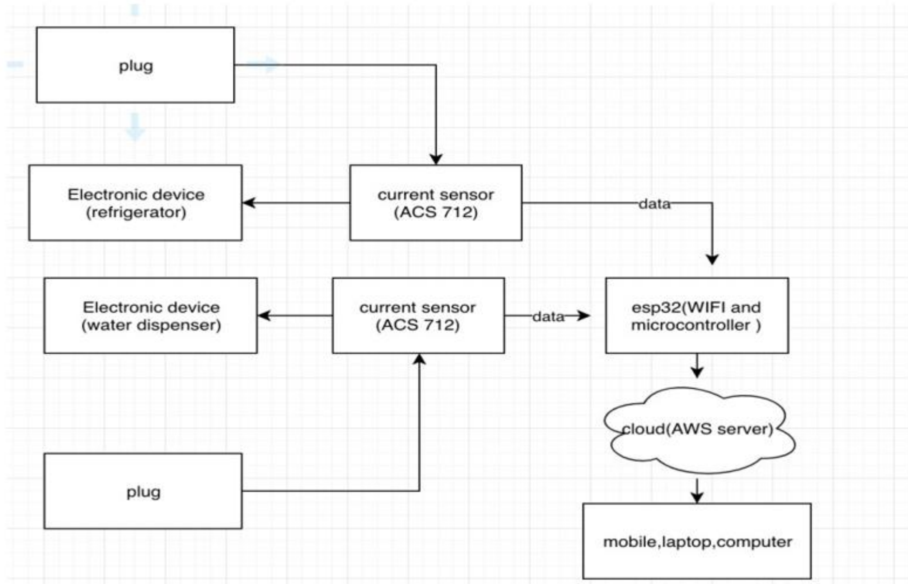

Fig. 2. Architectural Design of the proposed work.

4. GRID MANAGEMENT

We propose a digital filter, likely a Goertzel algorithm, which is commonly used for efficient computation of individual terms of a Discrete Fourier Transform (DFT). This is particularly useful in power systems for analyzing specific frequency components.

$\#define\ pi$ 3.14159265
$\#define\ NumPoints$ 200
$a = 0;\ b = 0;\ par = 0;$
 $-$ *pi is defined for trigonometric calculations.*
 $-$ *NumPoints sets the number of samples to process.*
Filter Coefficients
$reW\_f\ =\ 2.0 * cos(2.0 * pi/20);$
$imW\_f\ =\ 1.0 * sin(2.0 * pi/20);$
These calculate the real and imaginary parts of the complex exponential factor for the specific frequency of interest (in this case, corresponding to a period of 20 samples).
$for(i = 0; i < NumPoints; i++)$
$\{\ par\ =\ V(i)\ +\ reW\_f * a\ -\ b;$
 $b\ =\ a;$
 $a\ =\ par;\ \}$
This loop processes each sample $V(i)$ through the filter. It implements the core recursive equation of the Goertzel algorithm.
- Variables a, b, and par are initialized for the filter algorithm.
- These compute the real and imaginary parts of the DFT at the frequency of interest.

These compute the real and imaginary parts of the DFT at the frequency of interest. This algorithm efficiently computes the magnitude and phase of a specific frequency component in the input signal, which is crucial for analysing power quality issues such as harmonic distortion in non-sinusoidal conditions. This algorithm efficiently computes the magnitude and phase of a specific frequency component in the input signal, which is crucial for analyzing power quality issues such as harmonic distortion in non-sinusoidal conditions.

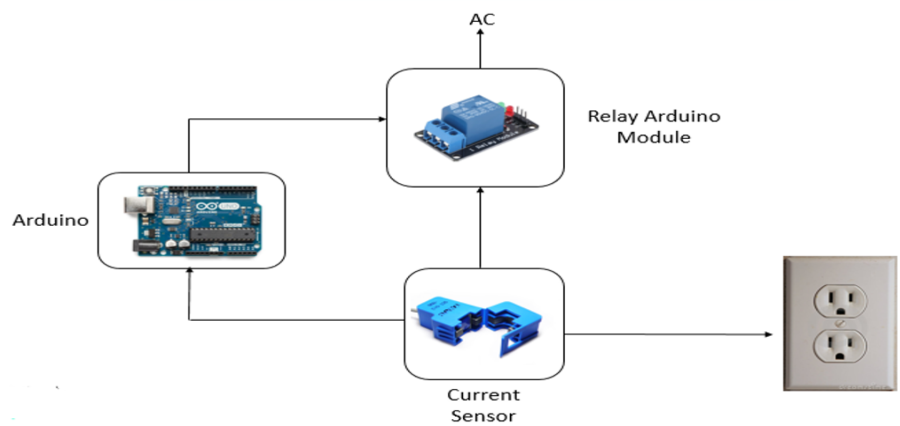

Fig. 3. Sensors to connect relay with sensors

Since IOT based smart homes, systems are vulnerable to hackers even today even if they pretend it is not, the statistic report says all over the world most system can be compromised within hours. The systems have implemented does not support backup redundancy system to make sure the systems available at any critical point due to many reasons. The following methodology suggest a way to secure the communication of the home against identified four main internal threats and how the backup system is to be implemented. The unit and cost of electrical energy consumed can be displayed on Arduino board's serial monitor. Ethernet communication [29] is the best solution to this issue. Ethernet's initial cost is only required and communication with the telephone/mobile network is achieved by small bandwidth as shown in Figure 4. From the flow chart diagram, Arduino's continuous monitoring of energy consumption via Ethernet can be seen. Using the counter code uploaded to the Arduino Uno board, the LDR sensor used as a button state in this project checks the consumer's unit and energy consumption costs. The prototype of the smart meter integrates a voltage and current measurement unit, and different communication protocols. It has a DC/DC isolated and integrated power converter, and three second-order Σ-Δ analog to digital converter, with sampling rate set to 1.024 MHz (an anti-aliasing analog low-pass filter is inserted on each ADC input, with cut frequency of 5 kHz). The output is a 24-bit data-word, proportional to the input signal level, with an output frequency of 1 kHz, obtained as an output of a digital low pass filter: the bandwidth of interest obtained is 40 Hz to 3.3 kHz as shown in Figure 4.

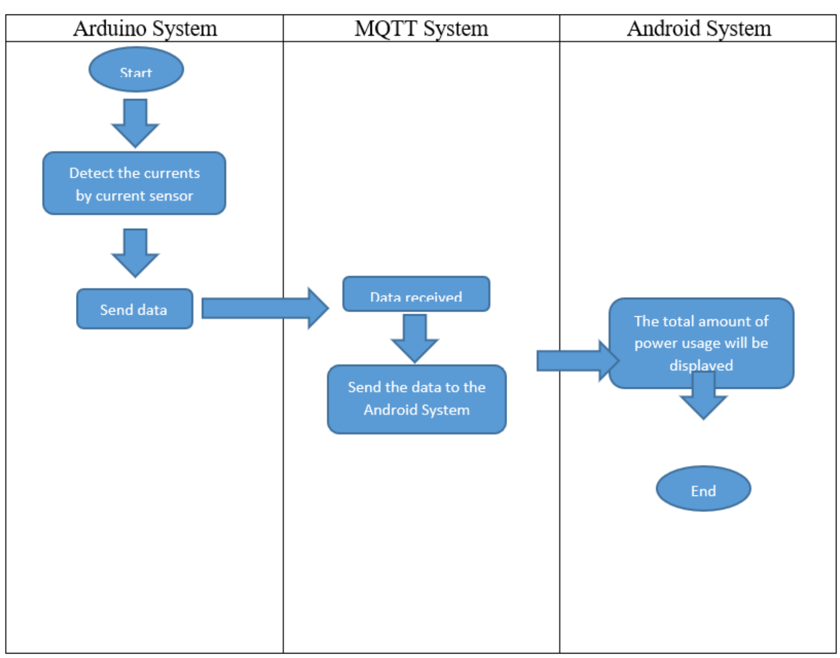

Fig. 4. Monitoring Power Usage using a MQTT system and a program

In the paper’s discussion part, we consider the various aspects of challenges and innovations in smart grid technology, with reference to objectives such as the measurement accuracy, data processing, security, and intelligent power objectives.

Therefore, the main purpose of the proposed study was to examine HFS methods used in contemporary power systems. It was observed that when Σ-Δ modulation was used, it enhanced the accuracy in analysis of signals due to loading and apodization of quantization noise. This advancement is important especially for metering power quality in the modern complex grid environment and thus it should help address our second requirement of improving the accuracy in the smart metering system. Another objective was to identify the efficiency of big data in smart grid applications because large number of users is characteristic of such systems. The case study we have conducted on the application of Spark SQL and RDD [30] showed that there is vast advancement over the conventional MapReduce systems. These technologies showed improved scalability and efficient power processing on large-scale power data analytics, satisfying this study's objective of determining improved data management for smart grids. As for the security objectives established in the current study, we reviewed existing methods of smart meters authentication. Consequently, our research outcome describes how public-key cryptography and SSH connections enhance mutual end-to-end secure communication between utilities and consumers. Nevertheless, we also found some unceasing issues in ensuring data consistency when the Web services are not available, which has pointed out the further research prospects. The present study also sought to assess intelligent power management solutions. We noted a positive development on methods of adaptive load balancing that involve communication between the devices to avoid getting to a condition of overloading the grid. Moreover, the study on how different sensors such as temperature or humidity sensors can be integrated in the context of appliance control algorithms pointed at possibilities for improving the energy consumption with a good level of comfort and stability. One of the key discoveries of the study, thus answering our research question aimed at defining the most important security threats of smart homes, was the fact that the systems were vulnerable to device impersonation attacks. This security threat can be lethal in impacting load forecasting and power scheduling algorithms since the devices that advertise themselves as high power devices are in fact high power ones. This study thus points to a need for enhancement in the methods of detecting and preventing such studies, an area that we consider requires ample investigation in the future.

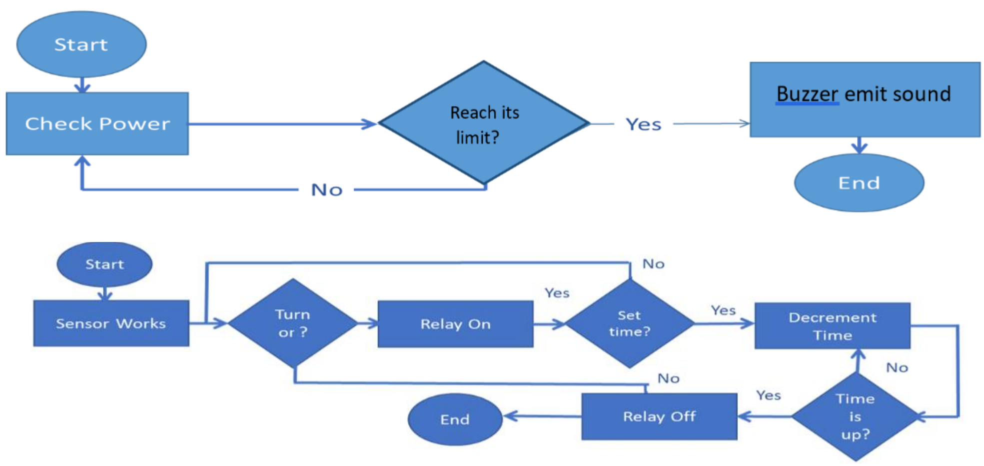

Fig. 5. Phase a Monitoring Power Usage

The most commonly used Big Data processing frameworks are Hadoop and Spark [31]. Especially because it integrates MLib, the machine learning library of Spark, we chose Spark. With the help of HTML, we designed webpage to function Arduino and Energy Meter. HTML stands for the expression of a hypertext markup. It is a standard markup language with Cascading Style Sheets (CSS) and JAVA scripts to generate web pages and web applications, establishing a triad of cornerstone systems for both the World Wide Web. Web browser receives HTML documents whether from a Webserver or local storage.

5. RESULTS AND DISCUSSION

AMI stands for Advanced Metering Infrastructure, which entails systems that can measure, gather, analyze and transmit information concerning distribution of utilities. These systems are important in the utility distribution network and are critical in the advancement of Smart City ideologies[31]. Basically, the server can decode messages when responses are received from the frame socket in general. On arriving at the evoked socket response of a radio command frame, the server locates for the corresponding socket address and retrieves the output socket command through an interface. This process entails acquiring power data instructions from the socket as mentioned in Figure 6. In response to these commands, the server transmits a response frame that contains power related information to the socket. Furthermore, there are default settings in the system to shut down any server configuration after a specific time limit has elapsed; this is since the use of the Arduino is not solely relied upon to perform tasks. To improve connectivity, the current Ethernet can be switched to Wi-Fi connectivity to improve the connection [32]. To this end, we sent the on/off messages from the MQTT corridor to the Smart Meters for testing. The data captured by the smart meters were then forwarded back to the MQTT corridor as depicted in Figure 6. To ensure reliability of the data in the database, real measurements were made from thermometers every 15 minutes [33]. In addition, a smart meter emulator was created which produced random data as means of testing the scalability of the entire system.

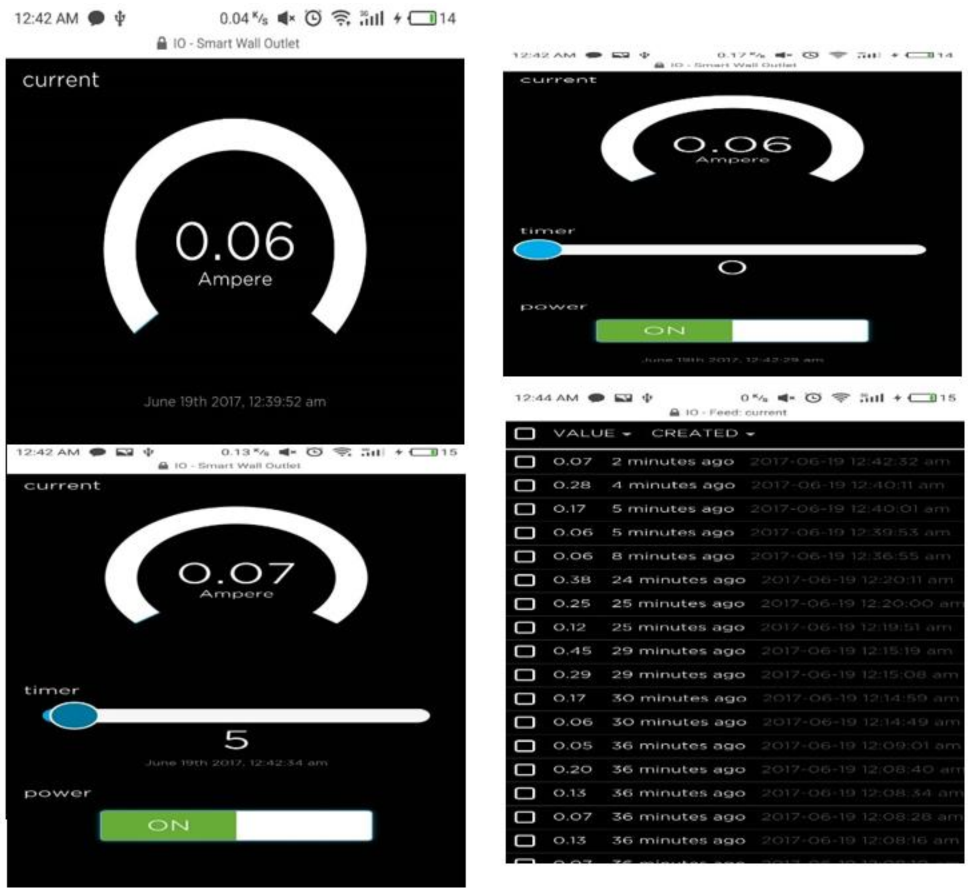

Fig. 6. Device design and implementation for a smart metering project

Initialize the hardware as per the requirements, scheme the controller according to the requirements, and gather data about input devices and output devices which work as instructed. Initialize hardware Wi-Fi and RFID [34][35]. The current or energy required for driving RELAY is far more like SSR. SSR requires 15amp to switching, when RELAY requires (30amp,50amp,90amp) as needed. The goal is to achieve better management of the networks provided by electrical energy, water and gas and an efficient balance between demand and consumption.

6. CONCLUSIONS

The proposed IoT-based smart energy monitoring system discussed in this paper can provide an efficient solution to enhance the electricity management in buildings. As it reveals the consumption patterns in granular detail, down to the device level, and allows remote control over the devices' use, it does not suffer from many of the shortcomings of the earlier metering systems. The use of cloud computing systems, machine learning algorithms, and mobile technologies in integration form a liberal platform for energy data acquisition, processing, and information delivery. Despite the limitations that are still present in the current IoT technologies especially in the aspects of data security and user uptake, this study provides a conception that the IoT technologies has the potential to revolutionize the process of energy management. The advancement of intelligent systems for monitoring human activity in future work should concentrate on the following: future work involves expanding the application of probabilistic models to anticipate human phases and behavior and refining the compatibility of the smart house with different smart house devices and apparatus. With the advancement in IoT technologies let's believe that such systems have a greater relevance in optimizing energy consumption in residential as well as commercial sectors.

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Conflicts Of Interest

The authors disclosure statement confirms the absence of any conflicts of interest.

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